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ON THE DAMAGE CAUSED BY WILDFIRE

THESIS
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EFFECT OF A CONTROLLED BURN ON THE DAMAGE CAUSED BY A WILDFIRE

INTRODUCTION

The catastrophic Carrizo-Cibecue fire of 1971 burned over 60 thousand acres on the Fort Apache Indian Reservation. Within the area covered by this wildfire lies the Foote Canyon Watershed, a portion of which was controlled burned in 1970. A handbuilt "scratch" fireline was constructed to limit the spread of this controlled burn, and the fireline was well-defined. This line is parallel to the slope and separates the two areas upon which the vegetation prior to the wildfire appears to have been similar. Also, from all available evidence, the wildfire entered both areas at the bottom of the slope at the same time. However, differences in damage to the low vegetation, soil, and residual timber stand from one side of this fireline to the other were remarkable. Virtually all standing timber in the area not treated by controlled burning is dead. Just a few feet away, on the side of the scratch line which was treated by controlled burning, the standing timber appears to have been essentially unaffected by the wildfire.

The Foote Canyon Watershed provided a unique opportunity for comparing differences in damage caused by wildfire on adjacent areas having two different fire histories. The entire watershed was burned over by the 1971 wildfire. Within the watershed, the controlled burn boundary was on a northeast facing slope with the same geographic features, slope gradients, vegetation type, and soil type. Paired plots were established on both sides of the controlled burn boundary and differences between

these plots were studied in detail. Such as: damage to the timber stand, changes in surface vegetation, changes in surface fuels, and changes in soil nutrient characteristics.

Periodic controlled burning has been shown to be an effective means of reducing wildfire hazard under at least some conditions (Weaver, 1943; 1951; Biswell and Schultz, 1956; Knorr, 1963; Kallander, 1969). Forest resource managers are in need of more complete information on the potential value of controlled burning for wildfire protection under conditions common to the Southwest (Weaver, 1947; 1967; Kallander, 1963).

The specific objectives of this study were to determine the differences in damage and the changes caused by the Carrizo-Cibecue wildfire on previously controlled burned and unburned areas on:

1. Tree and non-tree vegetation.
2. Surface fuels and soil nutrients.

The information obtained should be of value in determining the effectiveness of "low cost controlled burning" in reducing forest surface fuels.

METHODS

Sample Plots

Three pairs of 1/50 acre plots 100 ft. by 8.71 ft. were evaluated, one plot of each pair being located on the controlled burn side of the scratch line and one plot of each pair on the other side of the line. The two members of each pair were subjectively located in close proximity to each other on areas of uniform slope and exposure to represent as nearly as possible areas of physical similarity.

As most of the vegetation was killed by the wildfire in the area which was not controlled burned, the evidence used to pair the plots was based on the existing physical evidence including sizes and numbers of dead trees, charred remnants of trees, etc. Initial investigation indicated that enough evidence of this nature was available to make good subjective comparisons for determining the similarities that must have existed prior to the advent of fire.

Vegetation

Dominant overstory vegetation. The dominant overstory vegetation, ponderosa pine, was mapped in on all plots by 2 in dbh classes. On the plots burned by wildfires, the dbh was measured only on the standing dead trees killed by wildfire and estimated for the killed trees that were burned down to stumps (close to ground level). Some small trees in the area burned by wildfire only were probably so completely burned that no portions remained from which a record could be made. Tables 1 and 2 show the number of living and dead trees and tree seedlings found on the three plots pairs by species, dbh, basal area and their distribution by plots.

Surface vegetation and soil cover. The species present and species density in the surface vegetation was determined by means of counting and identifying all plants in 15, 1 meter by 2.65 meter quadrats (Table 3). Species cover and bare ground (Table 4) were estimated in each of the two fire history areas by measuring individual plant crown intercepts along three randomly located 100 foot lines (Canfield, 1941;1942). Bare ground included all distance not intercepted by surface vegetation (Table 4).

Litter depth measurements, taken at random (15 in each plot, using computer generated random position output), were used as indicators of the area of soil covered by organic matter. In addition, they were used as indicators of fire influence on the organic matter on the soil surface under the different conditions of fire history (Table 5). Measurements were made in all plots on each side of the scratch line, which as previously mentioned, had been made to stop the controlled fire and which served as the treatment boundary between the wildfire and the controlled burn-wildfire areas. Litter measurements consisted of the following:

1. Depth of loosely arranged fine and coarse surface litter (O1 layer).
2. Depth of compacted fine and partially decomposed litter (O2 layer).
3. Total depth of litter.

To develop guidelines for quantitatively estimating the fuels present on each plot, all of the organic material was removed and weighed by layers from subplots in the vicinity of unburned plots located throughout the area in which the fire studies are being conducted (total of 241 subsamples). This data was used to determine the total dry weights of the O1 and O2 layers in the following manner:

1. Two 1 ft. by 1 ft. sub-plots were located randomly in the vicinity of each plot of each plot pair in 3 undisturbed areas.
2. Three O1 and three O2 layer depths were measured for each subplot and the mean determined.
3. The O1 and O2 layers were collected from each subplot and placed in separate paper bags.
4. The bags of litter and organic materials were then oven dried for 24 hours at 120°F. and weighed.

5. The means were determined for each layer per cm of depth to obtain the fuel weight constants used to estimate the weights of fuels present in each plot.

The weights of the O1 and O2 layers were determined for all Foote Canyon plots (control and treatment plots) as follows:

1. Litter depths and decomposition layer depths were measured at 15 random points in undisturbed areas in each plot.
2. Dry weights of litter and decomposed layers were calculated for each plot by multiplying the mean litter depth of the plot by the dry weight constants determined from the litter weight studies.

Soils. Soils were collected for bioassay and chemical assay at the time the vegetation analyses and litter determinations were made. However, the detailed study of the chemical and textural characteristics of the soils have not been made due to lack of time and adequate funding.

The bioassays were made according to Jenny et al. (1951) and Wagle (1961). Germain's Great Lakes head lettuce was used as the indicator species to test for differences in macronutrient availability (N,P, and K) in the soils which had the different fire histories. The soils for bioassay were colledted as follows:

a. One 30 gallon sample was taken from undisturbed surfaces in each area from the 0-10 cm depth made up of a conglomerate mixture collected from 10 random locations. Material larger than 3/8 inch was screened out.
b. One 30 gallon sample was taken from each area from the 10-25 cm depth made up of a conglomerate mixture collected from 10 random

locations. Material larger than 3/8 inch was screened out.

Five seedling lettuce plants were planted in each of 60 pots having 4800 gms of soil per pot and grown for eight weeks. Four separate but simultaneous bioassays of 15 pots each were made on the soils from each depth (0-10 cm and 10-25 cm) collected from each of the two areas having different fire histories. Five treatments, each applied to plants in three pots (replicates), were used; a control (no nutrients added), a full treatment (N, P, and K added), a minus N treatment (P and K added), a minus P treatment (N and K added), and a minus K treatment (N and P added). Nutrient application rates were: nitrogen, 200 lbs/acre, phosphate 300 lbs/acre, and potassium 100 lbs/acre. Chemicals used for application were ammonium nitrate, mono-calcium phosphate, and potassium sulfate.

Statistical Analysis

General. The paired plot design was used to sample the areas involoved in this study. All of the plots were subjectively located on the same aspect in the same vegetation and soil types. According to Snedecor (1956, p.52), two plots next to each other are more likely to have similar environments and will respond more nearly alike than two at a distance; especially when subjectively selected for similarity in regards to vegetation, fuels, physiographic detail, etc.

The statistical analyses used on these plots consisted of the following:

1. After the initial date was collected, the mean, variances, standard deviation, standard error of the mean and confidence

intervals at the α=0.05 level were computed. These were used to determine whether or not the sub-sample numbers were adequate.

2. A two tailed F-test for homogeneity of the variance was used to determine if an equal variance or unequal variance type of t-test should be used when examining plot constituent similarities.
3. The appropriate type of t-test was used to compare species, family and litter make-up of the two historically different areas.

Litter or fuel analyses. More detailed statictical analyses were used to determine the effects of the two different fire histories on the O1 and O2 litter layers. Slope was brought into these analyses as an additional factor influencing the effect of fire on forest litter (surface fuels). Sampling of the O1 and O2 fuel depths, as previously implied, was a two stage cluster sampling techniques as described by Cochran (1963, chap. 10) with the first stage purposely chosen (slopes). The experimental design was that of randomized complete blocks with three replications. Each block was located on a specific slope and consisted of a pair of plots; one in the wildfire-only area and one in the wildfire area which had been pre-treated by controlled burning. Slopes of 36%, 20% and 0% were sampled with one of the plot pairs described earlier located on each slope. Because the slopes were selected and because the treatments were selected, blocks, treatments, and experimental error were considered fixed. Thus, a fixed 2x3x2 factorial analysis of variance model was used. Experimental error became interaction and the error term used for testing the null hypothesis of no difference was the result of the second stage of the two-stage cluster sampling scheme ,

i.e., sampling error (Steel and Torrie, 1960, chap. 11). The second stage sample consisted of the 15 randomly chosen O1 and O2 litter depths for each plot.

The statistical analyses of the relationships found in these litter studies are based on the assumption that the depths of the O1 and O2 layers on all slopes were approximately the same before the introduction of fire. Observations made elsewhere in unburned plots indicate that for any given aspect, with a given timber stand density, this assumption is reasonable.

RESULTS

Effect of Fire on Trees

Statistical analyses to test the effect of fire on the tree species were not possible since randomness was not associated with their selection, but rather, each plot of trees was considered a complete population. The differences in the effect of wildfire between the plots previously treated by controlled burning and those not treated by controlled burning are dramatic as summarized in Tables 1, 2, and 6. Only one living tree was found on the three plots located in the area invaded by wildfire-only out of a total of 22 trees that could be identified as having been present before the wildfire. It is probable that additional small living trees were present on these plots that were entirely consumed by the fire. In contrast, the wildfire killed only five trees out of a total of 30 trees on the three plots located in the area controlled burned prior to the wildfire, and all but one of these dead trees were in the smaller diameter classed (4 inches or less). Visual observations indicated that the

conditions found in these plots were representative of the areas in which they were located and that the drastic change in wildfire effect on the trees coincided with the fire line that was the boundary of the controlled burn area. Fuels on the forest floor within both areas had been burned by the wildfire but the effect in the controlled burned area was much less drastic, as will be shown later.

Another development of interest was the number of tree seedlings coming into the areas invaded by wildfire. A total of 96 seedlings were found in the three wildfire plots and none were found in the controlled burn-wildfire plots. (Tables 1a and 2a). Most seedlings occurred on the steepest plot (36% slope) which appeared to have been hardest hit by the wildfire. No ponderosa pine seedlings were observed in or out of the plots. Douglas-fir and Gambel oak seedlings predominated with one juniper seedling found in one plot.

Effect of Fire on Surface Vegetation

Appendix A gives a listing of all of the identified plant species found in the understory vegetation in all of the sites from which collections were made in the White Mountains and on the Mogollon Rim. Collection locations are shown for most species. A herbarium containing type specimens has been set up and is being maintained at McNary, Arizona. Table 3 shows the plant species present in the Foote Canyon study plot quadrats which were used as estimates of species densities. Comparing the two different treatment areas, six species were absent on the plots having the wildfire history and seven different species were absent on the plots having the controlled burn followed by wildfire history.

Three of the species, Senecio actinella, Koeleria cristata, and Ceanothus fendleri, found in the wildfire plots in fairly significant numbers, were not found in the controlled burn-wildfire plots. Other absences could have been due to sampling error. It is interesting to note that those species found in the greatest abundance showed relatively high densities under both fire histories. Table 4 shows the percent of ground covered by the understory plant species one year after the wildfire. The plots having the history of wildfire only had a significantly higher percentage of bare ground. One species, Koeleria cristata, provided the most ground cover on the wildfire plots and two species, Carex geophilla and Muhlenbergia virescens, were the main components of the ground cover on the controlled burn-wildfire plots.

Effect of Fire on Forest Fuels

Table 5 shows the depths of the O1 and O2 litter layers in the plots having the two different fire histories. Total litter depths for all samples, the maximum and minimum litter depths, the mean litter depths, the percent of bare mineral soil and the percent of soil surface having one millimeter or less of measurable organic matter, all indicate that wildfire-only has a much more significant effect on forest litter than does wildfire which follows a controlled burn. These results clearly show that the wildfire burned much more intensely on the plots not previously controlled burned. This data supplements the data shown in Tables 1, 2, and 6, which show the damage to trees resulting from the respective histories of wildfire-only and wildfire preceded by a controlled burn. In no sample was the litter completely removed by wildfire on

the area that had been controlled burned one year previously, while on the plots covered by wildfire-only, the litter was destroyed to mineral soil on 53% of the area in plot 1A (having a slope of 36%), on 33.3% of the area in plot 2A (having a slope of 20%) and on 13.3% of the area in 1A (having a slope of 0%). Additional evidence of the severity of the wildfire on these three plots was the presence of numerous surface rocks of varying sizes from 1 to several inches in diameter that had been heated to the point where pieces "spalled" or cracked off. This phenomenon was noted with much greater frequency on the steeper slopes. The data shown in Table 5 also indicate that the destructive influence of wildfire on the litter is related to the steepness of the slopes. More litter was removed and more mineral soil was exposed by wildfire-only on the steepest slope and the least was removed and exposed on the level. Very little difference occured in litter depths between slopes on the areas subjected to controlled burning before the wildfire.

Table 7 gives some litter weight constants that are applicable to the ponderosa pine type in the White Mountains and Mogollon Rim Country of Arizona. These constants are based on 241 raw data weight measurements and have been statistically evaluated as being well within a 95% probability of being accurate for the sites studied. They are more accurate than any other tables presently available for the type and area involved in this study. A separate paper covering this work will be written for publication.

Table 5 gives the litter weights, based on the constants in Table 8, found in the Foote Canyon plots and here the effect of wildfire-only in removing or destroying litter can be clearly seen in both the Ol and

02 litter layers. The 01 layer was the most severely damaged and the amount of litter removed is closely correlated with slopes.

On the level, wildfire had an appreciable influence only on 01 litter layer. The weight of the 02 layer in the wildfire only plot on the 0% slope when compared with the 02 layer on all three of the plots having the prior history of controlled burning was found not to be appreciably different. On the two steeper slopes sampled, the wildfire only was highly destructive to both the 01 and 02 litter layers.

Litter remaining on the sampled areas controlled burned prior to the wildfire, was apparently present in depths that were more than adequate to protect the soil surface from erosion and loss of the surface soil structure characteristics. The difference in litter distruction is probably responsible for the large number of tree seedlings found in the wildfire-only area due to a more complete exposure of the mineral soil on these plots. The loss of litter protection was greatest from wildfire on the steepest slopes where this protection was most needed to protect the mineral soil surface from erosion and loss of soil structural characteristics.

Table 9 shows data from three pairs located in the Buckskin study area with vegetation and environmental characteristics similar to Foote Canyon in which fuel measurements were made on the 01 and 02 layers in 1972. Part of the area was controlled burned in November of 1973 and after treatment measurements were made on the burned plots. These three plot pairs had approximately the same slope and aspects as the Foote Canyon plots. The data in Table 9 has not been statistically analyzed and is given for purposes of visual comparison with the results.

shown in Table 8. In making these comparisons it was assumed that the litter weights from Foote Canyon and the Buckskin study area were similar prior to the introduction of fire into Foote Canyon. This data is from a much larger study and will be analyzed as a part of that study.

When the means of the litter layer weights on the untreated plots shown in Table 9 are compared with the means of litter layer weights on the plots burned over by wildfire only in Table 8, litter comsumption is seen to amount to from 12 to 18 metric tons per hectare for the O1 layer and from 16.5 to 17.5 metric tons per hectare in the O2 layer.

When means of the litter layer weights in Table 8 for the plots controlled burned before the wildfire are compared with the means of the litter layer weights in Table 9 for the Buckskin plots before treatment, the only large quantities of litter destroyed in the control burned-wildfire plots occurred in the O1 litter layer, and was from 1.3 to 6.3 metric tons per hectare. The fuel consumption means due to controlled burning shown in Table 9 for the three A plots of 2.59 metric tons of litter per hectare in the O1 layer and 11.69 metric tons of litter per hectare in the O2 layer, imply that:

1. The controlled burn made in 1970 prior to the wildfire in Foote Canyon was not as hot or effective as was the Buckskin controlled burn made in the fall of 1973.
2. The controlled burn made in Foote Canyon in 1970 reduced the fuels appreciably only in the O1 litter layer, but this reduction was sufficient to alleviate the damage caused by a wildfire one year later.
3. Reduction in the fuels in O1 and O2 layers comparable to that

rendered by wildfire can be obtained by controlled burning without serious damage to the dominant woody vegetation (trees).

4. The crowns of the living trees in the controlled burned areas give immediate protection to the soil surface by: 1) Alleviating the direct impact of rain drops due to the protective canopy, 2) the presence of living rootlets of trees in the surface layers of mineral soil, 3) the immediate addition of surface litter due to needle drop which may even be somewhat accelerated as an after effect of the controlled burn. This effect will be tested in the larger Buckskin study.

Table 9 also indicates that the greatest fuel reduction from controlled burning may be obtained on the more moderate slopes (20%) than on either the level (0%) or steeper slopes (37%). However, slope did not appear to interact with fuel consumption in the Buckskin areas that were controlled burned (Table 9). This interaction between slope and fuel consumption during controlled burning will be tested statistically in the larger study.

Statistical Analysis of Litter. The statistical analyses that were made on the litter-fire relationships show that the differences that existed in litter weights and depths between areas having different fire histories were significant and highly significant. The litter layers used (O1 and O2) were identified according to Buckskin and Brady's (1969) definitions.

"O1: Organic horizon wherein the original forms of the plant and animal residues can be recognized by the naked eye."

"O2: Organic horizon in which the original plant and animal forms cannot be recognized by the naked eye."

Table 10 gives the treatment totals, various subtotals, and super-totals used in the computation of the sums of squares used to identify the significant differences in litter amounts resulting from the different fire histories, slopes, and litter layers sampled. The symbols used throughout the litter analyses are also given in this table.

Table 11 contains a summary of the 2x3x2 factorial analysis of variance results for the differences in litter amounts found in the Foote Canyon study. Highly significant differences were found in the litter depths on the different plots due to both fire history (factor C) and percent slope (factor B). These differences can be appreciated by referring to the totals shown in Table 10.

The highly significant interaction between fire history (factor C) and slope (factor B), indicates that the litter depths, when averaged over the O1 and O2, between the two fire histories, are not the same for the three slopes or that the effect of fire history on litter consumption varied very significantly with the steepness of slope (See totals of simple effect interactions of b_x, c_x, x equaling the various levels, in Table 10.)

The significant interaction between litter and fire (AC) implies that the differences within the O1 and within the O2 litter depths when averaged over all three slopes, are different as the result of their different fire histories (See differences in a_x c_x in the right hand column of Table 10).

The significant second-order interaction found to exist between litter, fire, and slope (ABC) suggests that AB interacted with C or AC interacted with B or BC interacted with A. Each factor (litter, fire,

and slope) exerted an influence on the results shown and any variation in one would materially influence the results due to one of the other factors.

An examination of the simple effects shown in Table 10 should illustrate and help with the interpretation of these first and second order interactions. Table 12 lists the simple effects of fire history (C) in relation to the slopes (b_1, b_2, b_3) and litter types (a_1, a_2) investigated. The C within b_x series indicates that the differences in litter depths between the wildfire-only and the controlled burn-wildfire areas, when averaged over the O1 and O2 layers, are highly significant for the 36%, 20% and 0% slopes. The C within a_x series indicates that the difference in litter depth response to fire between the O1 and O2 layers, averaged over all three slopes, is very significantly different.

Because the BC interaction has been shown to be highly significant and using the simple effect interaction shown in Table 12 (C within b_x for a_x series), the best interpretation of the significant ABC interaction shown in Table 12 is that there is a highly significant difference in the depths of the O1 litter layer between the areas having the two different histories on every slope studied. The mean O1 litter depths were always greater in the area controlled-burned one year prior to invasion by wildfire.

A highly significant difference between litter depths also existed in the O2 layer between the two areas on the 36% and the 20% slopes, but not on the 0% slope. The mean O2 depths, like the mean O1 depths, were greatest on the 20% and 36% slopes controlled burned prior to the onset of wildfire.

Effect of Fire on Soil Nutrients

Table 13 shows the dry weights and relative yields of the shoots and roots of lettuce indicator plants resulting from the bioassays made on the Foote Canyon soils having the two different fire histories. The relative yields for shoots indicate that the soils having different fire histories had different nutrient deficiencies within the same soil depths and between soil depths. A visual comparison of the differences in relative yields for shoots occuring between soils further indicates: 1) That soil nutrient availability was generally higher in the soils having the fire history of wildfire only. 2) That the greatest nutrient deficiencies existed at the 10-25 cm depth in the area which had been controlled burned prior to the advent of wildfire. The nutrients added to the latter did not increase the yields to the degree observed in the other soil samples tested. A factor which was limiting to the growth of the indicator plants apparently existed in the soil from the 10-25 cm depth with the controlled burning history which did not exist in the soil with the wildfire history. It is possible that soil acidity changes which were not measured may have been responsible for this difference. Whether this could be due to a greater removal of the litter source of organic acids or to the basic influence of more ash in the wildfire-only situation as discussed by Fowells (1934) or to both is only a matter of conjecture at this time, although the relatively high availability of nitrogen in the wildfire-only soil tends to favor Fowell's hypothesis.

Phosphorus (-P treatment, Table 13) was found to be deficient in both soils from the 0-10 cm depth and from one soil, with wildfire only history, from the 10-25 cm depth. A factor was or factors were responsible

for the overall depression in shoot yields in all five treatments (Table 7) in the soil from the 10-25 cm depth collected in the controlled burn-wildfire area that generally influenced all of the nutrient responses in this soil to a degree that the apparent deficiences are probably not real.

Nitrogen was less available in the soil from the 0-10 cm depth with controlled burning as a part of its fire history than in either of the soils (0-10 cm and 10-25 cm) with the wildfire-only history.

Potassium appeared to limit indicator plant growth in the soil from the 10-25 cm depth (-K treatment) with the wildfire-only history (Table 7). As this nutrient was not limiting to indicator plant growth in either of the surface (0-10 cm) soil (-K treatment) and least limiting in the soil having the wildfire-only history, both fire histories probably resulted in a release of potassium but in the controlled burned-wildfire situation the influence had not extended to the 10-25 cm depth.

The weights and relative yields shown for roots indicate the same kinds of numerical trends interpreted from the differences in shoot growth yields. However, the total yields and differences were so minimal that these results should only be used to supplement evidence derived from the shoot yields.

Statistical Analysis of Soils. Table 14 shows the results of the bioassays made on the Foote Canyon soils having the two different fire histories and statistical symbols identifying the relationships analyzed. Table 15 shows the results of the 2x2x5 factorial analysis of variance of these results.

Table 15 indicates that highly significant differences existed in nutrient availability in the soils collected from different depths (A),

the soils collected from areas having different fire histories (B), and responses of indicator plants to specific nutrient treatments (C).

The interaction between soil depth and the fire history of the soil (AB) and soil depth and nutrient availability (AC) were significant (Table 15). Non-significant differences existed (Table 15) for the interaction between soils having different fire histories and nutrient availabiltiy (BC), and interaction between the three factors of soil depth, soil fire history, and nutrient availability (ABC).

Further analysis of the soil depth-fire history interaction (AB, Table 16) and the soil depth-nutrient treatment interaction (AC, Table 17) shows that:

1. Differences in soil nutrient availability varied with soil depth and fire history and these differences were highly significant.
2. Soil from the 0-10 cm depth (A within C_1) had significantly more nutrients available than did soil from the 10-25 cm depth.
3. Soil from all sampled depths showed low but no significant differences in their response to the no phosphorous treatment (A within C_2) implying that the Foote Canyon soil is phosphorous deficienct.
4. Highly significant differences in potassium availability existed between soil depths (A within C_3). The soil from the 0-10 cm depth gave the best response to the no potassium treatment.
5. Highly significant differences in nitrogen availability existed between soil depths (A within C_4). The soil from the 0-10 cm depth having the wildfire-only fire history showed no deficency

with nitrogen deficiency indicated for others.

6. The highly significant differences that existed between the responses of soil to the full macronutrient treatment (A within C_5) indicate that a factor other than nutrient dificiences may have been responsible for the variation in response to the treatment in at least one sample.

A comparison of the means of the different nutrient treatments used in the bioassay (Table 18), using the Student-Newman-Kuels' Multiple Range Test (Newman, 1939), indicates phosphorous to be the least available nutrient. Nitrogen and potassium gave significantly higher yields than the controls and significantly lower yields than the complete NPK treatment indicating that both nitrogen and potassium were deficient enough to limit growth.

The same statistical analyses used on shoot yields were made on the lettuce indicator plant root yields obtained in the bioassay made on the Foote Canyon soils. Although the same numerical trends were found in root yields as were observed in the shoot yields, no significant differences were found in the main effects of fire history or soil depth nor in interactions between fire history and soil depth.

CONCLUSIONS

The statistical analyses support the differences observed in Foote Canyon which occurred in two similar areas having had different fire histories. The evidence strongly indicates that controlled burning one year prior to the advent of wildfire will alleviate most of the serious

damage to the dominant tree vegetation and the soil surface organic cover caused by wildfire. The results observed and the statistical analyses of these results together with comparisons made on similar sites in the larger study (Tables 8 and 9) also indicate that controlled burning under favorable conditions can remove nearly as much total surface fuel as can wildfire without seriously damaging the dominant vegetation which remains to give protection to the soil from compaction and erosion as described earlier.

Specifically, the following additional conclusions can be drawn from the data collected and the analyses made:

1. Although statistical analyses were not performed on the data collected on the differences in damage to the dominant overstory vegetation resulting from the two different fire histories of the area studied (Tables 1, 2, and 6), this data clearly shows that the controlled burning history gave almost complete protection to trees from a subsequent wildfire (25 living and 1 dead tree as opposed to 21 dead and 1 living tree). It further indicates that most of the damage resulting from wildfire in the controlled burned plots was in the smallest diameter classes (Table 6). This conclusion is supported by statistical analyses made on differences occurring in the two areas with the different fire histories showing that the history of wildfire-only exerted a significantly stronger effect on the surface vegetation and soil environment than did the history of controlled burning before the advent of wildfire.
2. Some changes occurred in species densities between the two areas

having different fire histories, but those species found in the greatest numbers were abundant under both fire histories, although these numbers did vary significantly in the case of two species (Table 3).

3. Vegetational ground cover was significantly less (by 5%) in the area having the history of wildfire only (Table 4).
4. The history of wildfire-only apparently resulted in the best seedbed for two tree species (Tables 1a and 2a).
5. The destruction of the organic layers of the soil in the area having the wildfire-only history by the fire moving uphill was directly related to the steepness of the slope. The greatest destruction occurred on the steepest slope and the least on the level (Tables 10, 11, and 12). The almost total destruction of the organic layers to mineral soil occurring on the steepest slope was probably the reason more tree seedlings were recorded in this situation, as a seed source from undamaged trees in the nearby areas having a prior history of controlled burning were equally available on all three slopes (Table 1).
6. The availability of the macronutrients N, P, and K for the Foote Canyon soils varied significantly with fire history. (Tables 13, 14, 15, 16, and 17).
   a. The highest nutrient availability, one year after the wildfire invaded both areas, occurred in both soil levels assayed (0-10 cm and 10-25 cm) in the area with the wildfire-only history (Tables 13 and 17).
   b. Phosphorus was the least available of the nutrients assayed (Tables 13, 15, 16, 17, and 18).

7. Litter weight constants statistically derived from measurements of the O1 and O2 litter layer depths collected for this study and a larger study of the ponderosa pine type along the Mogollon Rim south of Heber, Arizona are basic tools for future use in determining the weights of forest floor fuels (Table 7).
8. Fuel consumption under good controlled burning conditions, can approach that achieved by wildfire with none of the serious damage of catastrophic wildfire (Tables 8 and 9).
9. A light controlled burn which reduces the O1 litter layer, can greatly reduce the damage caused by a wildfire occurring one year later (Tables 8 and 9).

The results obtained and the conclusions arrived at in this study indicate that controlled burning is a valuable tool for alleviating the serious damage caused by a wildfire. However, the data is only relevant within the time period of the one year which elapsed between the controlled burn and the wildfire.

Further studies are needed to establish: 1) How long a controlled burn can exert an alleviating effect on the damage caused by catastrophic wildfire (or when to reburn); 2) Knowledge of vegetational and soil nutrient changes that occur over time after both wildfire and controlled burning; 3) How areas invaded by wildfires of different intensities and/or controlled burning vary in vegetation productivity; 4) Knowledge regarding the amounts of fuel consumed under different controlled burning conditions (temperature of the fire environment is a primary factor which should be studied in detail, with fuel moisture and wind relationships closely monitored); 5) Information on the aftereffects of fire on esthetics, land use priorities, and wildfire.

Table 1. Condition of Residual Trees[1] on Plots Located in a Timber Stand Invaded by Wildfire[2].

Plot 1A (36% slope)					Plot 2A (20% slope)				
DBH-OB[3] (inches)	No. of Trees	Species[4]	BA (sq. in.)	Class (living, dead)	DBH-OB[3] (inches)	No. of Trees	Species[4]	BA (sq. in.)	Class (living, dead)
1	1	PP	0.785	dead	1	1	PP	0.785	dead
3	1	PP	7.069	dead	3	1	DF	7.069	dead
5	2	PP	39.270	dead	5	1	PP	19.635	dead
7					7	1	PP	38.485	dead
9					9	2	PP	127.234	1 dead 1 living
11					11	1	PP	95.033	dead
13					13	2	PP	265.464	dead
15					15				
17					17				
19					19				
21					21				
23	1	PP	415.476	dead	23				
25	1	PP	490.874	dead	25				
27					27				
29	1	DF	660.520	dead	29				
Total	7	6 PP 1 DF	953.474 660.520	7 dead 0 living		9	8 PP 1 DF	546.636 7.069	8 dead 1 living

1. Observed one year after the wildfire.
2. Wildfire occurred in July, 1971.
3. Each number represents midpoint of 2" DBH class.
4. PP = ponderosa pine; DF = Douglas-fir.

Table 1 (con't).

Plot 3A (0% slope)				
DBH-OB[3] (inches)	No. of Trees	Species[4]	BA (sq. in.)	Class (living, dead)
1	1	PP	0.785	dead
3				
5				
7				
9	2	PP	127.234	dead
11				
13	1	PP	132.732	dead
15	1	PP	176.715	dead
17	1	PP	226.980	dead
19				
21				
23				
25				
27				
29				
Total	6	8 PP	664.446	6 dead 0 living

Table 1a. Tree Species Seedlings Observed in the Wildfire Plots

Species	Plot 1A 36% slope	Plot 2A 20% slope	Plot 3A 0% slope	Total
Douglas-fir	25	9	0	34
Quercus sp.	59	0	2	61
Juniperus sp.	0	0	1	1
Ponderosa Pina	0	0	0	0
Total:	74	9	3	96

Table 2. Conditions of Residual Trees[1] on Plots Located in a Timber Stand Invaded by Wildfire One Year After Control Burning[2].

Plot 1B (36% slope)					Plot 2B (20% slope)				
DBH-OB[3] (inches)	No. of Trees	Species[4]	BA (sq. in.)	Class (living, dead)	DBH-OB[3] (inches)	No. of Trees	Species[4]	BA (sq. in.)	Class (living, dead)
1	4	3 PP 1 DF	2.355 0.785	1 dead (PP) 3 living	1	1	PP	0.785	dead
3					3	4	PP	28.276	2 dead 2 living
5					5	1	PP	19.635	living
7					7	4	PP	153.940	living
9	1	PP	63.617	living	9	2	PP	127.234	1 dead 1 living
11					11				
13	1	PP	132.732	living	13				
15					15				
17					17				
19					19				
21					21	1	PP	346.361	living
23	2	PP	830.952	living	23				
25	1	PP	490.874	living	25				
27					27				
29					29				
Total	9	8 PP 1 DF	1520.530 0.785	1 dead 8 living		13	13 PP	676.231	4 dead 9 living

1. Observed one year after the wildfire.
2. Controlled burn treatment applied in the fall of 1970.
3. Each number represents midpoint of 2" DBH class.
4. PP = ponderosa pine; DF = Douglas-fir.

Table 2 (con't).

DBH-OB[3] (inches)	No. of Trees	Plot 3B (0% slope) Species[4]	BA (sq. in.)	Class (living, dead)
1	1	PP	0.785	living
3				
5				
7	1	PP	38.485	living
9				
11	3	PP	285.099	living
13	1	PP	132.732	living
15	2	PP	353.430	living
17				
19				
21				
23				
25				
27				
29				
Total	8	8 PP	810.531	0 dead 8 living

Table 2a. Tree Species Seedlings Observed in the Controlled Burn-Wildfire Plots.

Species	Plot 1B 36% slope	Plot 2B 20% slope	Plot 3B 0% slope	Total
Douglas-fir	0	0	0	0
Quereus sp.	0	0	0	0
Juniperus sp.	0	0	0	0
Ponderosa pine	0	0	0	0

Table 3. Species Present in Foote Canyon Study Plot Quadrats - Numbers and Relative Density. (Nomenclature follows that given by Kearney and Peebles, 1960.)

Species	Wildfire		Controlled Burn & Wildfire	
	No. of Plants	Relative Density (%)	No. of Plants	Relative Density (%)
Pinus ponderosa	7	2.90	7	2.45 ns
Composite, unidentified	5	2.17	5	1.75 ns
Hedeoma hyssopifolium	47	19.50	47	16.43 ns
Quercus gambelii	1	0.41	1	0.35 ns
Vivia americana	1	0.41	NO[1]	NO na
Lotus wrightii	1	0.41	NO	NO na
Senecio actinella	22	9.13	NO	NO na
Koeleria cristata	12	4.98	NO	NO na=
Ceanothus fendleri	5	2.17	NO	NO na
Solidago sparsiflora	3	1.24	NO	NO na
Calliandra humilis	3	1.24	NO	NO na
Parmelia sp. (lichen)	27	11.20	62	21.68 *
Carex geophila	72	29.88	89	31.11 ns
Muhlenbergia virescens	24	9.96	33	11.54 ns
Erigeron divergens	1	0.41	9	3.15 ns
Pedicularis centranthera	10	4.15	15	5.24 ns
Erigeron flagellaris	NO	NO	5	1.75 na
Sitanion hystrix	NO	NO	3	1.05 na
Pseudocymopteris montanus	NO	NO	2	0.70 na
Juniperus deppeana	NO	NO	2	0.70 na
Quercus grisea	NO	NO	2	0.70 na
Moss, unidentified	NO	NO	4	1.40 na
Total:	241	99.96%	286	100.0%

1 NO = Not observed in the quadrats

6 absences (NO) 7 absences (NO)

* Indicates significant at the $\alpha = 0.05$ level

ns means not significant

na means statistical test not applicable.

Table 4. Percent of Ground Covered by Understory Plant Species and Percent of Bare Ground Found in the Foote Canyon Plots.
(Nomenclature follows that given by Kearney and Peebles, 1960.)

Species	Wildfire Intercept Inches	Wildfire Cover (%)	Controlled Burn & Wildfire Intercept Inches	Controlled Burn & Wildfire Cover (%)
Composite, unidentified	0	NO[1]	9	0.25 na
Quercus gambelii[2]	1	0.03	0	NO na
Vicia americana	1	0.03	0	NO na
Lotus wrightii	2	0.06	0	NO na
Senecio actinella	0	NO	0	NO na
Koeleria cristata	65	1.81	0	NO na
Ceanothus fendleri	5	0.14	0	NO na
Parmelia sp. (lichen)	10	0.28	13	0.36 ns
Carex geophila	26	0.72	195	5.42**
Muhlenbergia virescens	24	0.67	87	2.42 ns
Erigeron divergens	1	0.03	0	NO na
Pedicularis centranthera	0	NO	3	0.08 na
Sitanion hystrix	16	0.44	11	0.31 ns
Juniperus deppeana[2]	0	NO	12	0.33 na
Muhlenbergia longiligula	0	NO	10	0.28 na
Astragalus tephrodes	8	0.22	0	NO na
Cirsium wheeleri	8	0.22	0	NO na
GROUND COVERED:	167 in.	4.65%	340 in.	9.45%
BARE GROUND:	3,433 in.	95.35%	3,260 in.	90.55%

1 NO = Not observed on the intercepts
2 Only trees less than 3 ft. high were measured for coverage.

** Significantly different from the wildfire region at the α=0.01 level.
ns means not significant.
na means statistical test not applicable.

Table 5. The Depth in Millimeters of the O1 and O2 Litter Layers in Paired Plots With Two Different Fire Histories.

Sample No.	Plot 1A[1] O1	O2	Total	Plot 2A O1	O2	Total	Plot 3A O1	O2	Total
1	0.0	0.0	0.0	2.0	3.0	5.0	0.0	0.0	0.0
2	1.0	0.0	1.0	5.0	0.0	5.0	5.0	5.0	10.0
3	3.0	0.0	3.0	0.0	0.0	0.0	5.0	1.0	6.0
4	1.0	1.0	2.0	1.0	2.0	3.0	0.0	10.0	10.0
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	30.0
6	5.0	10.0	15.0	5.0	0.0	5.0	15.0	2.0	17.0
7	0.0	0.0	0.0	0.0	0.0	0.0	15.0	5.0	20.0
8	1.0	2.0	3.0	0.0	0.0	0.0	25.0	20.0	45.0
9	0.0	0.0	0.0	0.0	0.0	0.0	10.0	25.0	35.0
10	0.0	0.0	0.0	4.0	3.0	7.0	10.0	30.0	40.0
11	0.0	1.0	1.0	1.0	0.0	1.0	12.0	15.0	27.0
12	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	1.0
13	0.0	0.0	0.0	1.0	3.0	4.0	10.0	30.0	40.0
14	0.0	0.0	0.0	5.0	4.0	9.0	10.0	17.0	27.0
15	1.0	0.0	1.0	10.0	3.0	13.0	15.0	30.0	45.0
Total	12.0	14.0	26.0	34.0	19.0	53.0	133.0	220.0	353.0
Max.	5.0	10.0	15.0	10.0	4.0	13.0	25.0	30.0	45.0
Min.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	0.80	0.93	1.73	2.27	1.27	3.53	8.87	14.67	23.53
% area to mineral soil[3]			53.3			33.3			6.7
% area having 1mm. or less organic matter			73.3			46.7			13.3

1 "A" plots are those located in the wildfire-only area.
2 "B" plots are those located in the controlled burn-wildfire area.
3 Mineral soil is soil devoid of a measurable litter cover. Percentages are used as indicators of surface area devoid of litter.

Table 5 (con't).

Sample No.	Plot 1B[2] 01	02	Total	Plot 2B 01	02	Total	Plot 3B 01	02	Total
1	10.0	15.0	25.0	20.0	5.0	25.0	10.0	10.0	20.0
2	20.0	5.0	25.0	25.0	5.0	30.0	20.0	7.0	27.0
3	3.0	10.0	13.0	15.0	2.0	17.0	10.0	8.0	18.0
4	20.0	15.0	35.0	15.0	1.0	16.0	20.0	15.0	35.0
5	20.0	25.0	45.0	10.0	2.0	12.0	5.0	15.0	20.0
6	15.0	15.0	30.0	20.0	7.0	27.0	25.0	10.0	35.0
7	3.0	35.0	38.0	30.0	7.0	37.0	16.0	11.0	27.0
8	15.0	10.0	25.0	7.0	8.0	15.0	25.0	20.0	45.0
9	40.0	25.0	65.0	25.0	15.0	40.0	20.0	20.0	40.0
10	20.0	30.0	50.0	10.0	5.0	15.0	26.0	20.0	46.0
11	15.0	12.0	27.0	30.0	25.0	55.0	25.0	10.0	35.0
12	5.0	30.0	35.0	20.0	5.0	25.0	20.0	15.0	35.0
13	25.0	25.0	50.0	17.0	22.0	39.0	20.0	25.0	45.0
14	15.0	30.0	45.0	17.0	7.0	24.0	20.0	20.0	40.0
15	10.0	15.0	25.0	5.0	20.0	25.0	17.0	18.0	35.0
Total:	236.0	297.0	533.0	266.0	136.0	402.0	279.0	224.0	503.0
Max.	40.0	35.0	65.0	30.0	25.0	55.0	26.0	25.0	46.0
Min.	3.0	5.0	13.0	5.0	1.0	12.0	5.0	7.0	18.0
Mean	15.73	19.80	35.53	17.73	9.07	26.80	18.60	14.93	33.53
% area to mineral soil[3]			0.0			0.0			0.0
% area having 1mm. or less organic matter			0.0			0.0			0.0

Table 6. Total Damage to Residual Timber Caused by Wildfire on Plots Located on Adjacent Areas- One Previously Treatment by Controlled Burning.

Wildfire					Controlled Burn & Wildfire				
DBH-OB[1] (inches)	No. of Trees	Species[2]	BA (sq. in.)	Class (living, dead)	DBH-OB[1] (inches)	No. of Trees	Species	BA (sq. in.)	Class (living, dead)
1	3	PP	2.355	dead	1	6	5 PP	3.925	2 dead (DF-dead)
							1 Df	0.785	4 living
3	2	1 PP	7.069	dead	3	4	PP	28.276	2 dead
		1 DF	7.069						2 living
5	3	PP	58.905	dead	5	1	PP	19.635	living
7	1	PP	38.485	dead	7	5	PP	192.425	living
9	4	PP	254.465	3 dead	9	3	PP	190.851	1 dead
				1 living					2 living
11	1	PP	95.033	dead	11	3	PP	285.009	living
13	3	PP	398.196	dead	13	2	PP	265.464	living
15	1	PP	176.715	dead	15	2	PP	353.430	1 dead
									1 living
17	1	PP	226.980	dead	17				
19					19				
21					21	1	PP	346.361	living
23	1	PP	415.476	dead	23	2	PP	830.952	living
25	1	PP	490.874	dead	25	1	PP	490.874	living
27					27				
29	1	DF	660.520	dead	29				
Total	22	20 PP	2164.556	21 dead		30	29 PP	3007.202	5 dead
		2 DF	667.589	1 living			1 DF	0.785	25 living

1. Each number represents midpoint of 2" DBH class.
2. PP = ponderosa pine; DF = Douglas-fir.

Table 7. Litter Weight Constants Derived for the O1 and O2 Layers in the Ponderosa Pine Type of the Fort Apache Indian Reservation and Adjacent Areas.

Layer	Depth	gms/cm^2	cms/meter^2	meter tons/ha
O1	1 cm	0.0808	808.0	8.08
O2	1 cm	0.2180	2180.0	21.80

Layer	Depth	lbs/ft^2	lbs/yd^2	tons (short)/acre
O1	1 in	0.4180	3.785	9.144
O2	1 in	1.1350	10.211	24.730

Table 8. Unit Area Dry Litter Weights Found in the Foote Canyon Plots Having Two Different Fire Histories

Plot Pair No.	Slope %	Weight in gms/meter^2				Weight in metric tons/ ha			
		Wildfire only		Control Burn & Wildfire		Wildfire only		Control Burn & Wildfire	
		01	02	01	02	01	02	01	02
1	36	64.6	203.3	1,273.0	4,320.0	.65	2.03	12.73	43.20
2	20	184.6	270.0	1,433.0	1,984.0	1.84	2.78	14.33	19.84
3	0	716.6	3,203.4	1,500.0	3,140.0	7.17	32.04	15.00	31.48
Total:		964.8	3,203.4	4,206.0	9,444.0	9.65	36.85	42.06	94.44
Mean:		321.6	1,225.6	1,402.0	3,148.0	3.22	12.28	14.02	31.48
		Weight in lbs/ft^2				Weight in tons (short)/acre			
1	36	.0132	.0415	.2603	.8850	.288	.906	5.68	19.30
2	20	.0375	.0568	.2933	.4368	.818	1.240	6.40	8.83
3	0	.1467	.6560	.3080	.6440	3.198	14.270	6.70	14.00
Total:		.1974	.7543	.8616	1.9658	4.304	16.416	18.77	42.13
Mean:		.0658	.2514	.2872	.6553	1.435	5.305	6.26	14.04

Table 9. Unit Area Dry Litter Weights Found on Three Plot Pairs in the Buckskin Area Before and After Controlled Burning Explicating Fuel Consumption.

Weight in gms/meter^2

Plot Pair No.	Slope %	Before Treatment Plot A 01	Before Treatment Plot A 02	Before Treatment Plot B 01	Before Treatment Plot B 02	After Treatment Plot A 01	After Treatment Plot A 02	Fuel Consumption Plot A 01	Fuel Consumption Plot A 02
E8	37	2206.64	1945.58	1858.48	2858.70	1926.00	1286.46	280.64	659.12
E4	20	1933.52	2484.33	1298.00	3343.00	1494.80	1447.94	438.72	2036.39
W2	0	2255.52	3218.84	1442.96	2684.68	2197.60	2405.94	57.92	812.90
Total:		6395.68	8648.75	4599.44	8886.38	5618.40	5140.34	777.28	3508.41
Mean:		2131.89	2882.97	1533.15	2962.13	1872.80	1713.45	259.09	1169.47

Weight in metric tons/ha

E8	37	22.07	19.46	18.58	28.59	19.26	12.86	2.81	6.59
E4	20	19.34	34.84	12.98	33.43	14.95	14.48	4.39	20.36
W2	0	22.56	32.19	14.43	26.85	21.98	24.06	0.58	8.13
Total:		63.97	86.49	45.99	88.87	56.19	51.40	7.78	35.08
Mean:		21.32	28.83	15.33	29.62	18.73	17.13	2.59	11.69

Table 10. Depth*(mm) of Two Litter Layers (A) on Three Slopes (B) with Litter Previously Treated and not Previously Treated with Fire (C).

Litter Layer=A	Fire History=C	Slope = B: 36% = b_1	20% = b_2	0% = b_3	Total=$b_1+b_2+b_3$
01 = a_1	Previously treated =c_1	236=($a_1b_1c_1$)	266=($a_1b_2c_1$)	279=($a_1b_3c_1$)	781=(a_1c_1)
	Not previously treated = c_2	12=($a_1b_1c_2$)	34=($a_1b_2c_2$)	133=($a_1b_3c_2$)	179=(a_1c_2)
	Total = c_1+c_2	248=(a_1b_1)	300=(a_1b_2)	412=(a_1b_3)	960=(a_1)
02 = a_2	Previously treated = c_1	297=($a_2b_1c_1$)	136=($a_2b_2c_1$)	224=($a_2b_3c_1$)	657=(a_2c_1)
	Not previously treated = c_2	14=($a_2b_1c_2$)	19=($a_2b_2c_2$)	220=($a_2b_3c_2$)	253=(a_2c_2)
	Total = c_1+c_2	311=(a_2b_1)	155=(a_2b_2)	436=(a_2b_3)	910=(a_2)
Total=a_1+a_2	Previously treated = c_1	533=(b_1c_1)	402=(b_2c_1)	503=(b_3c_1)	1438=(c_1)
	Not previously treated = c_2	26=(b_1c_2)	53=(b_2c_2)	353=(b_3c_2)	432=(c_2)
	Total = c_1+c_2	559=(b_1)	455=(b_2)	848=(b_3)	1870=G

* Each value is the total of 15 subsamples.

Table 11. Result Summary of 2x3x2 Factorial Analysis of Variance of the Difference in Fire History and Slope Effect on the O1 and O2 Litter Layers.

Source of Variation		F
C	(Fire history)	14.97**
B	(Slope)	116.58**
BC	(Slope x Fire history)	11.06**
AC	(Litter layer x Fire history)	4.52*
ABC	(Litter layer x Slope x Fire history)	4.11*

* Indicates significance at the $\alpha = 0.05$ level; referred to in this text as significant.

** Indicates significance at the $\alpha = 0.01$ level; referred to in this text as highly significant.

Table 12. Summary of Simple Effects of Fire History (C)

Source of Variation	F
C within b_1	88.80**
C within b_2	42.09**
C within b_3	7.78**
C within a_1	83.50**
C within a_2	37.60**
C within b_1 for a_1	34.68**
C within b_1 for a_2	53.03**
C within b_2 for a_1	37.20**
C within b_2 for a_2	9.46**
C within b_3 for a_1	14.70**
C within b_3 for a_2	0.09ns

ns means not significant.
** Indicates significance at the $\alpha = 0.01$ level

Table 13. Dry Weights and Relative Yields of the Shoots and Roots of Lettuce Indicator Plants Grown in the Foote Canyon Soils[1].

Soil Origin		Nutrient	Weight in gms.		Relative Yield (%) Within Soils[2]		Between Soils[3]	
Depth	Fire History	Treatment	Shoots	Roots	Shoots	Roots	Shoots	Roots
0-10 cm	Wildfire only	Control	2.300	0.161	48	103	55	109
		NPK	4.813	0.156	100	100	111	105
		PK (-N)	4.102	0.164	85	105	99	111
		NK (-P)	2.080	0.174	43	112	50	117
		NP (-K)	4.173	0.195	87	124	100	131
	Controlled burned one year prior to Wildfire invasion	Control	2.015[3]	0.160[3]	46	108	46	108
		NPK	4.165[3]	0.148[3]	100	100	100	100
		PK (-N)	2.535	0.338	61	228	61	228
		NK (-P)	1.651	0.142	40	99	40	99
		NP (-K)	3.416	0.195	82	131	82	131
10-25 cm	Wildfire only	Control	1.193	0.189	35	65	29	128
		NPK	3.369	0.293	100	100	81	130
		PK (-N)	2.763	0.209	82	71	66	141
		NK (-P)	1.337	0.114	40	39	32	77
		NP (-K)	2.233	0.163	66	56	54	111
	Controlled burned one year prior to Wildfire invasion	Control	0.668	0.064	275	168	16	43
		NPK	0.243	0.038	100	100	6	24
		PK (-N)	0.332	0.059	137	155	8	39
		NK (-P)	0.531	0.078	218	205	13	53
		NP (-K)	0.289	0.047	119	128	7	32

1 Soil bioassay was carried out over the same period of time under the same growing conditions with the same indicator species.

2 Yields relative to the full fertilizer treatment (yield from NPK treatment = 100%) for each soil depth and soil fire history according to Jenney et al. (1951).

3 All between soils yields are shown relative to the full fertilizer treatment (yield from NPK treatment = 100%) given to the soil from the 0-10 cm depth having a fire history of a controlled burn one year prior to the invasion of wildfire.

Table 14. Weight*(gms) of Lettuce Shoots for Two Studied Soil Depth Classes (A) of Two Soil History Types (B) Resulting from Five Different Nutrient Treatments (Bioassays) (C).

Soil depth= A	Treatment = C	Soil history type = B: No controlled burn/ wildfire = b_1	Controlled burn/ wildfire = b_2	Total= b_1+b_2
0-10 cm = a_1	No treatment = c_1	2.300 = $(a_1b_1c_1)$	2.015 = $(a_1b_2c_1)$	4.315= (a_1c_1)
	No P = c_2	2.080 = $(a_1b_1c_2)$	1.651 = $(a_1b_2c_2)$	3.731= (a_1c_2)
	No K = c_3	4.173 = $(a_1b_1c_3)$	3.416 = $(a_1b_2c_3)$	7.589= (a_1c_3)
	No N = c_4	4.102 = $(a_1b_1c_4)$	2.535 = $(a_1b_2c_4)$	6.637= (a_1c_4)
	Full treatment = c_5	4.813 = $(a_1b_1c_5)$	4.165 = $(a_1b_2c_5)$	8.978= (a_1c_5)
	Total=$c_1+c_2+c_3+c_4+c_5$	17.468 = (a_1b_1)	13.782 = (a_1b_2)	31.250= (a_1)
10-25 cm = a_2	No treatment = c_1	1.193 = $(a_2b_1c_1)$	0.668 = $(a_2b_2c_1)$	1.861= (a_2c_1)
	No P = c_2	1.337 = $(a_2b_1c_2)$	0.531 = $(a_2b_2c_2)$	1.868= (a_2c_2)
	No K = c_3	2.233 = $(a_2b_1c_3)$	0.289 = $(a_2b_2c_3)$	2.522= (a_2c_3)
	No N = c_4	2.763 = $(a_2b_1c_4)$	0.332 = $(a_2b_2c_4)$	3.095= (a_2c_4)
	Full treatment = c_5	3.369 = $(a_2b_1c_5)$	0.243 = $(a_2b_2c_5)$	3.612= (a_2c_5)
	Total=$c_1+c_2+c_3+c_4+c_5$	10.895 = (a_2b_1)	2.063 = (a_2b_2)	12.958= (a_2)
Total = a_1+a_2	No treatment = c_1	3.493 = (b_1c_1)	2.683 = (b_2c_1)	6.176= (c_1)
	No p = c_2	3.417 = (b_1c_2)	2.182 = (b_2c_2)	5.599= (c_2)
	No K = c_3	6.406 = (b_1c_3)	3.705 = (b_2c_3)	10.111= (c_3)
	No N = c_4	6.865 = (b_1c_4)	2.867 = (b_2c_4)	9.732= (c_4)
	Full treatment = c_5	8.182 = (b_1c_5)	4.408 = (b_2c_5)	12.590= (c_5)
	Total=$c_1+c_2+c_3+c_4+c_5$	28.363 = (b_1)	15.845 = (b_2)	44.208= G

* Each value (in gms) is a total fo three replicates (i.e., a sum over blocks) of five plants each.

Table 15. Result Summary of 2x2x5 Factorial Analysis of the Variance of the Difference in Nutrient Availability in the Foote Canyon Soils Haavng Two Different Fire Histories.

Source of Variation	F
A (Soil Depth Class)	72.89**
B (Fire History)	34.60**
C (Nutrient Treatment)	9.41**
AB (Soil Depth Class x Fire History)	5.84*
AC (Soil Depth Class x Nutrient Treatment)	2.65*
BC (Fire History x Nutrient Treatment)	2.31ns
ABC (Soil Depth Class x Fire History x Nutrient Treatment)	0.88ns

ns means not significant.
* Indicates significance at the $\alpha = 0.05$ level.
** Indicates significance at the $\alpha = 0.01$ level.

Table 16. Summary of Simple Effects of the Soil Depth Class-Fire History Interaction (AB)

Source of Variation	F
A within b_1	19.08**
A within b_2	60.66**

** Indicates significance at the $\alpha = 0.01$ level.

Table 17. Summary of the Simple Effects of the Soil Depth-Nutrient Treatment (AC) Interaction

Source of VAriation	F values
A within c_1	6.65*
A within c_2	3.83ns
A within c_3	28.36**
A within c_4	13.85**
A within c_5	31.79**

* Indicates significance at the $\alpha = 0.05$ level.
** Indicates significance at the $\alpha = 0.01$ level.
ns means not significant.

Table 18. Nutritional Availability (C) Bioassays Made in the Foote Canyon Soils. SNK Multiple Range Test.[1]

Treatment	Control	Nk(-P)	NP(-K)	PK(-N)	NPK
Means	1.544	1.3998	2.433	2.528	3.148
Significantly Different[2] (α = 0.05)					

1 Test performed after significant differences were found among the nutrient treatments simple effects.

2 Those treatments underlined by a common line are not significantly different.

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